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Long-Run Demand Forecasting for Nonfuel Mineral Commodities

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LONG-RUN DEMAND FORECASTING FOR NONFUEL MINERAL COMMODITIES

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I. Introduction*

To fulfill its responsibilities under the Forest and Rangeland Renewable Resources Planning Act of 1972, the U.S. Forest Service conducts supply and demand studies for the many mineral commodities found on public lands. As a part of this effort, it forecasts the U.S. demand for mineral commodities up to 50 years in the future.

Purpose and Scope

In the past, experts have produced these long-run demand forecasts for nonfuel mineral commodities on the basis of their subjective judgment. The underlying causal relationships governing the growth in demand were not identified, and no statistical techniques were used. The U.S. Forest Service, believing a more rigorous approach was needed, asked the Colorado School of Mines and specifically the authors of this report to develop an alternative forecasting methodology based on the intensity of metal use technique and to apply the proposed methodology to two mineral commodities.

The two commodities examined are copper, a widely used metal, and sand and gravel, a non-metallic mineral product used largely in the construction sector. For each, conditional forecasts are developed for U.S. demand for the years 2020 and 2050. These forecasts are conditional in the sense that they take as given forecasts for U.S. gross

* The authors are grateful to Phillip C. F. Crowson, Hans H. Landsberg, and Marian Radetzki for their helpful comments on this project and willingness to serve on an External Advisory Committee for the project. We would also like to thank Deborah J. Shields for her insights and support.

domestic product (GDP) for these two years, which the U.S. Forest Service plans to obtain from independent macroeconomic forecasting services.

Organization

This final report on the project is divided into six sections. The second section, following this introduction, examines various forecasting methodologies commonly used to predict the future demand for mineral commodities. The third section describes the methodology we propose. The fourth and fifth sections use our propose methodology to generate forecasts for the U.S. demand for copper and for sand and gravel for the years 2020 and 2050. The sixth and final section examines the advantages and disadvantages of our forecasting approach.

II. Methods of Forecasting the Demand for Mineral Commodities

Forecasters have used a variety of different approaches to predict the future demand for mineral commodities. This section briefly describes these methods along with their strengths and weaknesses. This information allows the reader to place the methodology we propose within a conceptual and historical framework, and to compare its advantages and disadvantages with other approaches.

Expert Judgments

Expert judgment is the approach, as noted earlier, that the U.S. Forest Service has relied upon in the past for its long-term demand forecasts for nonfuel mineral commodities. Mineral commodity specialists generate such forecasts on the basis of their knowledge of market trends--recent trends in demand, anticipated changes in the technologies of using or producing the commodity, the expected changes in the growth of end-use sectors, and any other considerations that the experts believe are likely to affect significantly future demand for the commodity of interest.

The U.S. Bureau of Mines has widely applied this forecasting methodology. Past time trends in the demand for mineral commodities are extended 20 or more years into the future. The resulting predictions are then adjusted upward or downward on the basis of the judgment of the Bureau's mineral commodity specialists.

Using such an approach, for example, Ageton and Greenspoon (1970, pp. 548-9), the copper commodity specialists at the U.S. Bureau of Mines, estimated in the late 1960s that the U.S. copper demand in the year 2000 would be between 8.1 and 13.0 million metric tons. Jolly (1986, pp. 216-20), the copper commodity specialist in the mid-1980s, using a similar approach some 15 years later estimated that U.S. copper demand in the year 2000 at between 2.4 and 3.5 million metric tons. Comparable forecasts for the U.S. demand for sand and gravel in the year 2000 are found in Cooper (1970, pp. 1192-6) and in Davis and Tepordei (1986, pp. 701-2).

This approach almost always produces forecasts that at the time seem reasonable. Whether this is because whatever recognized experts say is prima facia considered

reasonable or because experts seriously advancing propositions widely considered absurd are known to quickly lose their reputation as experts, we cannot say. Perhaps both are relevant.

Expert judgments are, however, subjective. Rarely are the relationships presumed to govern the future evolution of demand explicitly identified, so it is difficult to assess the means by which they are developed. In short, they have to be accepted on faith, the belief that experts through some subjective process that they themselves may not understand can weigh the important determinants of demand and with considerable accuracy predict their net effect over the next several decades. This is a serious disadvantage. It eliminates one important means of appraising the forecasts themselves. In addition, it reduces or eliminates the contribution that forecasting can make to our understanding of the important forces shaping the demand for mineral commodities over time.

Technology Based Forecasts

President Truman's Commission on Materials Policy (better known as the Paley Commission after its chairman William S. Paley) pioneered this approach in its 1952 report Resources for Freedom (President's Materials Policy Commission, 1952). Resources for the Future also used this approach a decade later to make long-run demand forecasts in its comprehensive volume Resources in America's Future (Fischman and others, 1962).

In some ways the technology based approach is similar to the expert judgment approach: historical trends are projected into the future with appropriate adjustments for

the expected effects of technological change and other important determinants. As the name suggests, however, technology based forecasts generally entail a much greater effort to identify the important technological developments likely to influence mineral commodity demand, both developments on the supply side affecting price and developments on the demand side affecting the number of end uses and the extent of consumption in these uses. Design engineers and others in the important end-using industries are consulted in an effort to identify the important new technologies likely to affect the demand for particular mineral commodities over the next several decades.

This approach tends to be more qualitative than quantitative, though it is much more explicit in identifying the underlying forces, particularly the anticipated technological developments, considered in developing the final forecasts. Its record, as Landsberg (1975) has pointed out, is mixed. Both the Paley Commission and Resources for the Future accurately identified the important developments affecting the demand for mineral commodities in a number of cases. In others, they overestimated the importance of certain technologies while underestimating the importance of others. The net effect, thanks to offsetting errors, were reasonable accurate forecasts. In some cases, however, the errors were not offsetting and the forecasts ended up quite wide of the mark. The biggest drawback of the technology approach, however, is the amount of resources, both in term of time and costs, it requires. The Paley Commission employed a staff of analysts over a two year period. The Resources for the Future study also involved hundreds of man-hours over an extend period of time.

Econometric Forecasts

This forecasting technique typically involves specifying a demand equation. For example, copper demand in year t (Q_t) is often presumed to depend on the price of copper in year t (P_t), the price of a close substitute, such as aluminum, in year t (PS_t), and the level of economic activity measured by GDP or some other variable during year t (Y_t). Other determinants of copper demand may be added as well, such as lagged variables to take account of effects that persist over more than one year. The relationship between these variables is normally assumed to be linear or log linear as illustrated in the following equations:

$$Q_t = \alpha_0 + \alpha_1 P_t + \alpha_2 PS_t + \alpha_3 Y_t + \varepsilon_t$$

$$\ln Q_t = \beta_0 + \beta_1 \ln P_t + \beta_2 \ln PS_t + \beta_3 \ln Y_t + \mu_t$$

Where the α's and β's are parameters that are estimated using regression analysis or some other econometric procedure, and the ε_t and μ_t are disturbance terms added to take account of the net influence of all omitted variables and any stochastic variation in demand.

Once the parameters are estimated, conditional forecasts for the demand for copper, or any other commodity, in some future year t can be derived using anticipated values for the price of copper and the other independent variables.

Demand equations, such as those shown above, may stand alone as a single equation model. Often, however, they are part of a larger model that includes equations for supply, inventories, price, and other endogenously determined variables. An early and now classical effort to use a multiple equation econometric model to forecast copper

demand and supply is found in Fisher, Cootner, and Baily (1972). One can find more on econometric models of mineral commodities and their use in forecasting in Burrows (1975), Bozdogan and Hartman (1979), Guvenen, Labys, and Lesourd (1991), and Pei (1996).

Econometric demand forecasts have the advantage that they clearly identify the relationships on which they are based. They are generally presumed to be more suitable for near term forecasts covering the coming year or two than long-run forecasts. This is in part because they have difficult in capturing the influence of new technology. This variable's influence on demand, while modest in the short run, is often very important over the long run. In addition, econometric forecasts assume the estimated parameters are constant not only over the historical period on which they are based, but over the forecast period as well. This is much more likely to be the case in the short run than the long run.

Time Series Models

A time series model, unlike a multi-equation regression model, does not relate a dependent variable to a set of independent variables. A forecast or prediction of future behavior is based solely on the past behavior of the variable in question. Time series models are primarily used when little is known about the determinants of the variable in question, or when conducting forecasts where the determinants would also have to be forecasted in order to generate a forecast of the dependent variable. A time series model therefore avoids the need to identify cause and effect relationships.

Extrapolation models are often used for long term forecasting. The objective of an extrapolation model is to smooth the time series in question so that short-term fluctuations are removed. Once short-term fluctuations are removed, a line of best fit is produced through historical data. This line can then be extended to future years in order to obtain a forecast for the year in question.

Examples of extrapolation models are linear trend models and exponential growth curves. Linear trend models are used when there is a belief that the historical series will increase in constant amounts each time period. For instance, $Y_t = c_1 + c_2T_t$, where Y_t represents demand at time t, T_t is a time variable, c_1 is the constant or Y-intercept, and c_2 is the slope coefficient (which reflects the amount by which demand increases each time period). Exponential growth curves are used when demand is thought to increase or grow by a constant percentage over time. In this instance, $\ln(Y_t) = c_1 + c_2T_t$. Other common types of extrapolation models reflect a quadratic or logistic trend.

Another time series model employs a moving average. When the likely value for the demand in future periods is simply the average of its previous values, a simple moving average model, such as that shown below, can be used to generate a forecast.

Model $\quad f(t) = 1/3\ (Y_{t-1} + Y_{t-2} + Y_{t-3})$

Forecast $\quad Y_{t+1} = 1/3\ (Y_t + Y_{t-1} + Y_{t-2})$

Weights can also be applied to moving average models, so that more recent values have a greater impact on the forecast than previous values.

If the demand for a mineral commodity is generated by a random process, a stochastic model should be used. An ARIMA--autoregressive moving average--model incorporates the stochastic process into its forecasts. As a result, each value in the series (Y_1, Y_2, Y_3,...Y_T) is drawn randomly from a probability distribution.

An ARIMA model is made up of two parts, an autoregressive component and a moving average component. In an autoregressive model, Y_t is generated by a weighted average of past observations with a random disturbance term in the current period.

$$Y_t = \varnothing_1 Y_{t-1} + \varnothing_2 Y_{t-2} + \ldots \varnothing_p Y_{t-p} + \delta + \varepsilon_t$$

The $\varnothing$s represent the weighted average of past observations and p represents the number of autoregressive components. δ represents the mean of the stochastic process or probability distribution.

In a moving average model, Y_t is generated by a weighted average of random disturbances going back q periods.

$$Y_t = \mu + \varepsilon_t - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2} - \ldots - \theta_q \varepsilon_{t-q}$$

where the θs represent the weighted average of the disturbance terms ε_t , ε_{t-1},... etc. The symbol μ is the constant term and q represents the number of periods.

Combining the moving average and autoregressive models creates an ARMA(p,q) model where q denotes the number of moving average components and p the number of autoregressive components.

$$Y_t = \varnothing_1 Y_{t-1} + \varnothing_2 Y_{t-2} + \ldots \varnothing_p Y_{t-p} + \delta + \mu_t - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2} - \ldots - \theta_q \varepsilon_{t-q} + \varepsilon_t$$

The ARMA model can be used when the times series is stationary. Stationary simply means that the characteristics (mean and standard deviation) of the series are fixed over time. If the series shows either a gradual increase or decrease over time, then it has a non-stationary characteristic. When a series is not stationary, it must be converted to a stationary process by differencing. The number of times a series has to be differenced in order to produce a stationary series is known as the order of homogeneity, and is denoted with the letter d. If a series has to be differenced, an ARIMA model is used instead of a ARMA model. The only difference between the two is that the ARIMA model differences the time series to produce a stationary series.

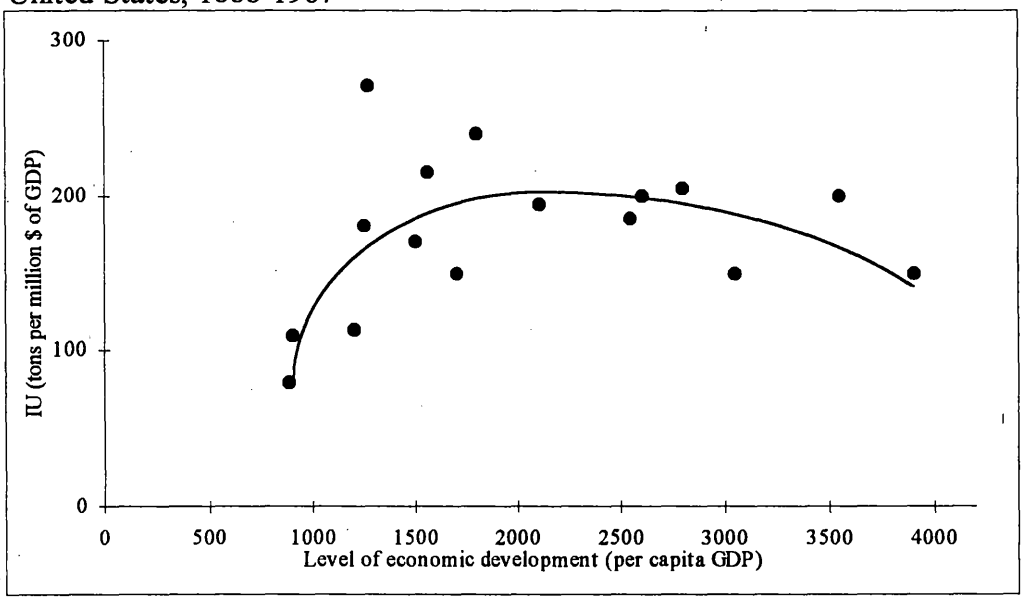
ARIMA models --as well as other stochastic time series models-- have not been particularly successful at long term forecasting. Their comparative advantage seems to lie with short term forecasting, and they are today often used for this purpose.

Intensity of Use Hypothesis

The International Iron and Steel Institute (1972), Malenbaum (1973, 1975, 1978), and others have used the intensity of use hypothesis to make long-run demand forecasts for mineral commodities. This procedure assumes that the intensity of metal use is a function of a country's level of economic development or per capita income. The nature of this relationship is determined empirically, either using time series data for a single country as illustrated in Chart 1, or using a cross section of countries at any particular time. As shown in Chart 1, its general shape typically is presumed to reflect an inverted U-shaped

curve. When per capita incomes are very low, the domestic economy is largely subsistence farming, and material needs are also low. As development occurs and per capita income rises, manufacturing, construction, and other material-intensive activities expand, causing the intensity of metal use to rise. As development continues, the need for automobiles, houses, and machinery eventually is filled, and demand shifts toward services and other, less-material intensive products.

Chart 1: Relationship Between Intensity of Use and per Capita Income in the United States, 1888-1967



Source: Organization for Economic Cooperation and Development, Forecasting Steel Consumption. 1974. (Paris: OECD), p. 58.
Notes: GDP is measured in constant 1963 dollars; points shown are five year averages, through which a free-hand curve has been drawn.

A major advantage of this approach is that long-run demand forecasts are easy and cheap to produce. The U.S. demand for copper in year t (Q_t), for instance, is simply the product of the intensity of copper use in the United States in year t (IU_t) and the country's GDP in year t (Y_t):

$$Q_t = IU_t \times Y_t$$

Macroeconomic forecasts of GDP are readily available from a number of sources, and the expected value of the intensity of copper use in the forecast year can be generated from an estimated intensity of use curve, similar to that shown in Chart 1, on the basis of expected per capita income.

As pointed out by Radetzki and Tilton (1990, pp. 26-30), however, there are other factors influencing the intensity of metal use than per capita income. In particular, new technology and material substitution are likely to shift the true intensity of use curve over time. For the most part, these shifts are likely to be downward as a result of new resource-saving technologies. There may be exceptions, however. The material substitution fostered by the introduction of the aluminum beverage can for a number of years shifted aluminum's intensity of use curve up in the United States.

In any case, since the true intensity of use curve is shifting over time, the intensity of use curve estimated on the basis of time series consumption data is really a hybrid. Using this curve to forecast future intensity of copper use and in turn copper demand is valid only if the influence of the other determinants of intensity of use are closely correlated with changes in per capital income. Given the discrete and unpredictable behavior of technological change and its effects, this seems unlikely.

III. Proposed Methodology and Forecasts

This section proposes an alternative method for forecasting the demand for nonfuel mineral commodities. Sections 4 and 5 then use this method to forecast first the U.S. demand for copper and then the demand for sand and gravel for the years 2020 and 2050. The approach we propose is somewhat similar to the intensity of use hypothesis described earlier in that demand forecasts are derived from predictions of intensity of use. Our approach, however, does not assume that the sole or overriding determinant of intensity of use is the level of economic development as reflected by per capita income. In addition, it produces both a point forecast and a probability distribution based on Monte Carlo simulation. Given the inherent uncertainty associated with forecasting long-run demand, the probability distribution is of considerable interest.

Procedural Steps

There are nine specific steps in our forecasting approach:

1. Identify the economic sectors principally responsible for the consumption of the mineral commodity whose demand is being forecasted. In the case of copper, as the next section will point out, five sectors account for almost all of the U.S. demand for copper--building and construction, transportation, industrial machinery and equipment, electrical and electronic products, and consumer and general products.

2. Collect intensity of use data over a historical or base period for each of the major consuming sectors identified in step 1, and the estimate the semi-log functional form that best fits the intensity of use data using the following equation:

$$\ln IU_{it} = \alpha_0 + \alpha_1 T_t + \varepsilon_t$$

Where IU_{it} is the intensity of use for the ith sector in year t, T_t is a time variable, ε_t is the standard disturbance term, and the α's are parameters to be estimated. A semi-log relationship that makes the log of IU_t, rather than IU_t, a function of time is proposed because intensity of use normally is expected to decline asymptotically over time toward some floor value as a result of new resource-saving technology.

3. Estimate the expected intensity of use in the desired forecast year for each of the major consuming sectors by extrapolating the curves derived in step 2.

4. Obtain sectoral GDP forecasts for the forecast year for each major consuming sector. Such forecasts are available from a number of macroeconomic forecasting services. They can also be derived in other ways. The following two sections, for example, use three possible growth scenarios for the economic sectors principally responsible for the consumption of copper and of sand and gravel. The high growth rate scenario assumes each sector will expand in the future at the rate it grew over the 1960-73 period, a time of relatively rapid growth. The low growth rate scenario assumes each sector will expand in the future at the rate it grew over the 1973-93 period, a time of relatively slow growth. The medium growth rate scenario assumes each sector will expand in the future at the rate it grew over the entire 1960-93 period. Since sectoral GDP forecasts are derived from external sources, rather than determined endogeneously, our proposed approach generates

conditional forecasts, in the sense that they depend on and vary with the forecasts used for sectoral GDP.

5. With the sectoral intensities of use generated in step 3 and the sectoral GDP forecasts generated in step 4, calculate point forecasts of future demand using the following equation:

$$Q_t = \Sigma\ (IU_{it} \times Y_{it})$$

Where Q_t is predicted demand for the forecast year t, IU_{it} is the estimated intensity of use for the ith sector in the forecast year t, and Y_{it} is the estimated GDP for the ith sector in the forecast year t.

6. Estimate the standard deviation for each major consuming sector's estimate of intensity of use for the forecast period. One approach would simply use the standard deviations for each sector's intensity of copper use over the base period. However, given the tendency for intensity of metal use to decline over time, this is likely to overstate the true standard deviation for the forecast year, particularly if the forecast year is far into the future. For instance, as following section notes, the mean value for the intensity of copper use in the industrial machinery sector was 6.48 for the base period--the years 1960-93--and its standard deviation was 2.46. By 2050, one of the two forecast years of interest, the intensity of copper use in the industrial machinery sector is expected to be only 0.48, and it is likely that its standard deviation will have fallen substantially as well.

To avoid this potential bias, we assume instead that the coefficient of variation remains the same during the forecast period and the base period. The coefficient of variation is defined as the ratio of the standard deviation to the arithmetic mean, and is

used as an indicator of relative dispersion. This implies that the standard deviation of the intensity of copper use in each sector can be estimated for the forecast year by multiplying the standard deviation for the base period by the ratio of the expected value of intensity of use during the forecast year to its mean value during the base period. For instance, if the intensity of use in a particular sector has a mean value of 4.0 and a standard deviation of 2.0 over the base period, and has an expected value of 1.0 in the forecast year, then its estimated standard deviation for the forecast year is 0.5.

7. Using data from the base period, estimate the correlation coefficients between the intensities of use for different major consuming sectors. A negative correlation coefficient between two sectors, for example, indicates that when the intensity of use in one increases the intensity of use in the other tends to decrease.

8. With the correlation coefficients from step 7, run a Monte Carlo simulation. This entails the construction of a probability distribution for the expected intensity of use for each major consuming sector in the forecast year. The expect GDP for each sector, in contrast, is assumed to be known (given exogeneously) and invariant. Using the probability distribution for intensity of use, and taking into account the correlations between sectoral intensities of use, 2000 estimates of total demand are simulated for the forecast year. From these results, one can determine the mean forecast, the lowest forecast, the highest forecast, and the probability distribution around the mean forecast.

9. Conduct a sensitivity analysis by varying the expected sectoral intensities of use in the forecast year to determine how the forecasts of future demand derived in step 8 are affected.

Assumptions

The forecasting procedures just described rests on a number of assumptions. Among the more important are the following:

o Demand for the mineral commodity will remain over the forecast period heavily concentrated in the major consuming sectors identified in step 1 for the base period.

o Intensity of use in each of the major consuming sectors has followed an exponential decline over the base period and will continue to do so over the forecast period. As a result, a semi-log functional specification produces accurate forecasts of the future IU of each sector.

o The correlations between sectoral intensities of use that existed during the base period will continue into the future.

IV. Copper

This section employs the procedures just described to generate forecasts of U.S. demand for copper in the years 2020 and 2050. The base period providing the historical data for these forecasts covers the years 1960-93.

The major copper consuming sectors of the economy, whose identification constitutes **step 1** in our procedures, are building and construction, transportation, industrial machinery and equipment, electrical and electronic products, and consumer and

general products. Together these five sectors account for over 90 percent of all the copper consumed in the United States during the 1960-93 period.

The intensity of copper use for each of these sectors, measured in terms of metric tons of copper consumed by the sector per million real (1987) dollars of sectoral GDP, is shown in Chart 2. The GDP by sector and the copper consumption by sector, on which the curves in Chart 2 are based, are found in Charts 3 and 4. The data for these three charts are given in Appendices 1.1-1.3, along with their sources.

Chart 2: Intensity of Copper Use by Sector in Tons per Million (1987) Dollars, 1960-1993

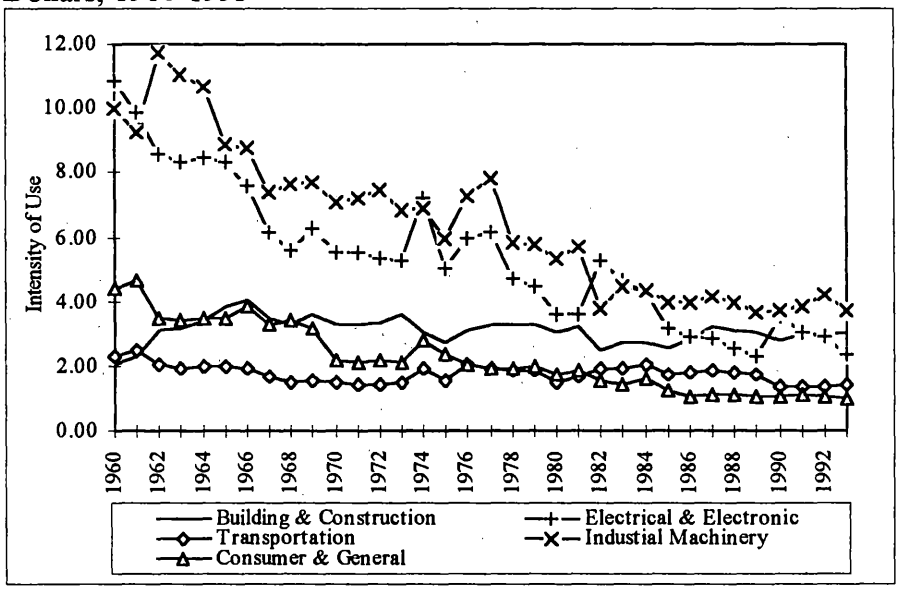


Chart 3: Gross Domestic Product by Sector, 1960-1993

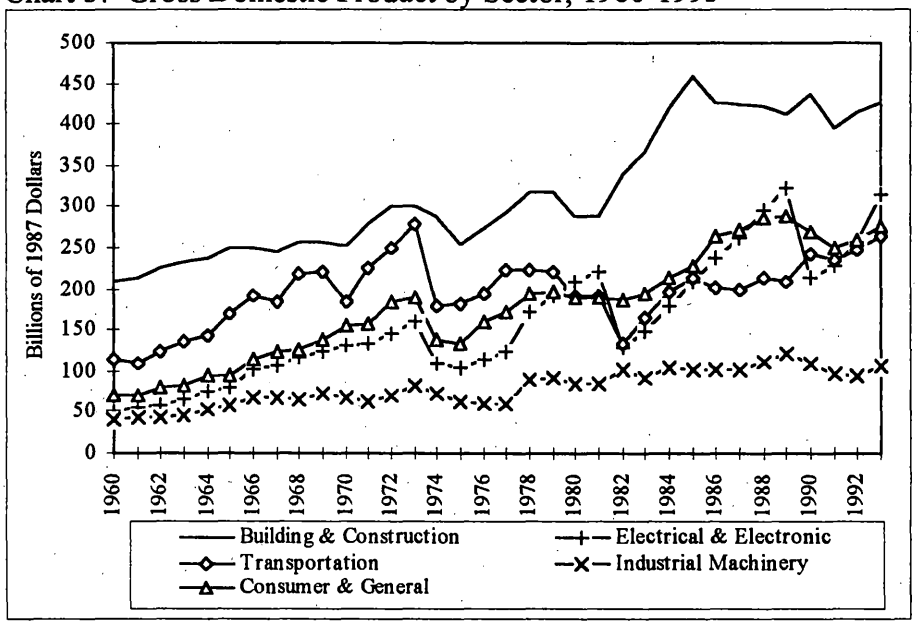
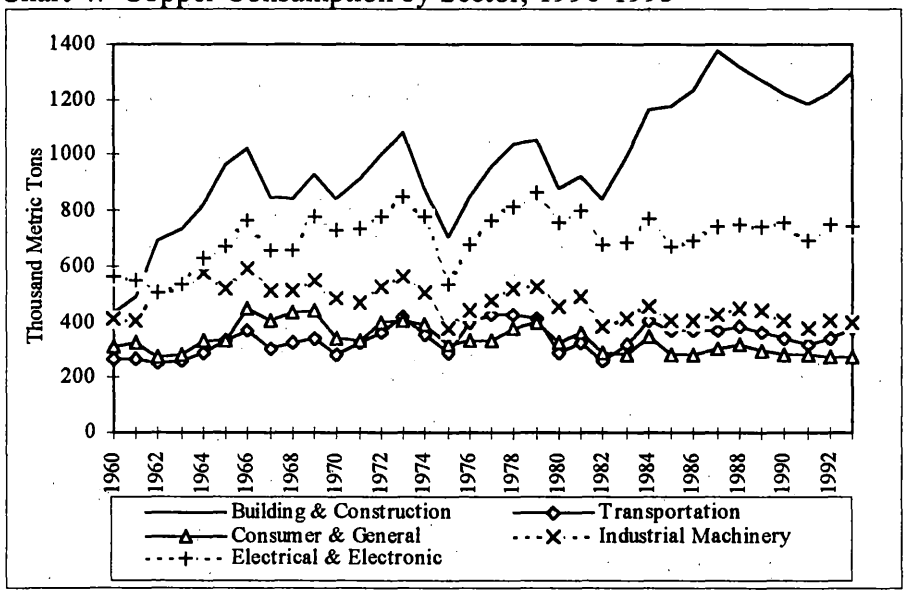


Chart 4: Copper Consumption by Sector, 1996-1993



The semi-log functional form that best fit the intensity of use data shown in Chart 2 was estimated using generalized least squares regression analysis. The results, which fulfill **step 2** of our procedures, are depicted in Charts 5-9 for each of the copper-intensive sectors, and are reported in Appendix 2.1. The forecasts of sectoral intensity of use derived from extrapolating these curves to the years 2020 and 2050--**step 3** of our procedures--are given in Table 1.

Table 1: Intensity of Use Forecasts by Sector, 2020 and 2050, in Metric Tons per Million Real (1987) Dollars of GDP

Sector	2020 IU	2050 IU
Building & Construction	2.23	1.73
Electrical & Electronic	0.84	0.25
Transportation	1.00	0.67
Industrial Machinery	1.35	0.48
Consumer & General	0.27	0.07

Chart 5: Intensity of Copper Use Trend in Tons per Millions (1987) Dollars for the Building and Construction Sector

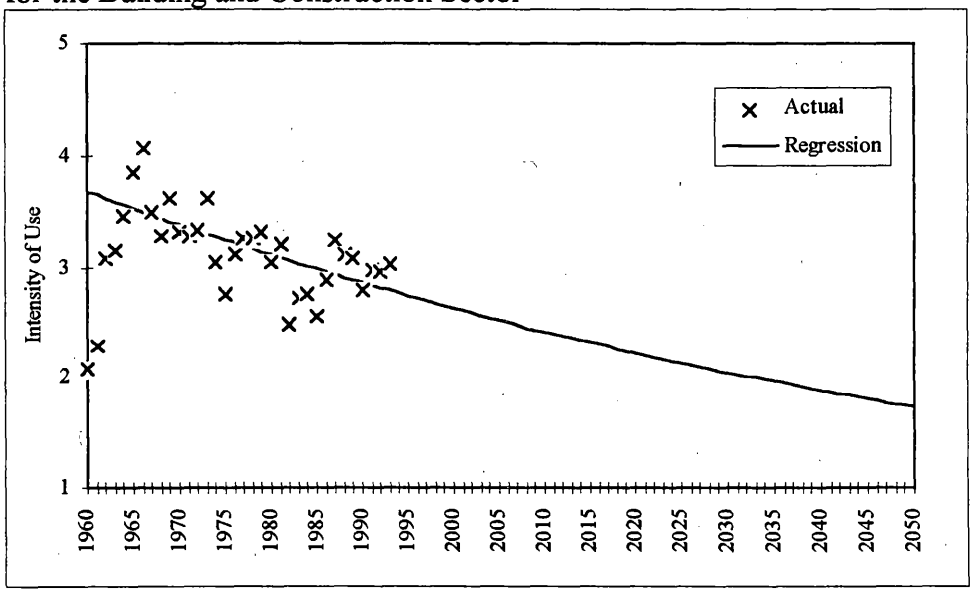


Chart 6: Intensity of Copper Use Trend in Tons per Million (1987) Dollars for the Electrical and Electronic Sector

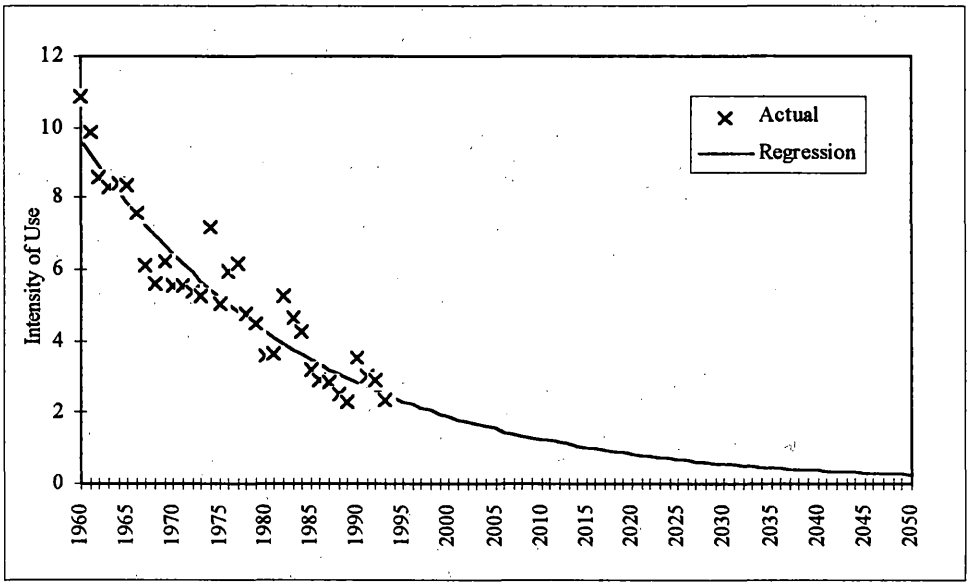


Chart 7: Intensity of Copper Use Trend in Tons per Million (1987) Dollars for the Transportation Sector

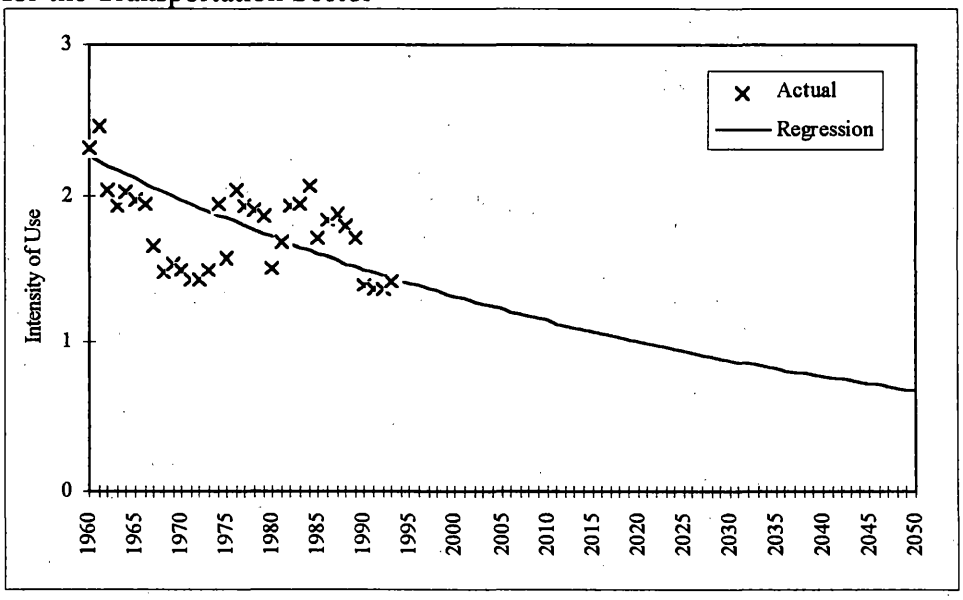


Chart 8: Intensity of Copper Use Trend in Tons per Million (1987) Dollars for the Industrial Machinery Sector

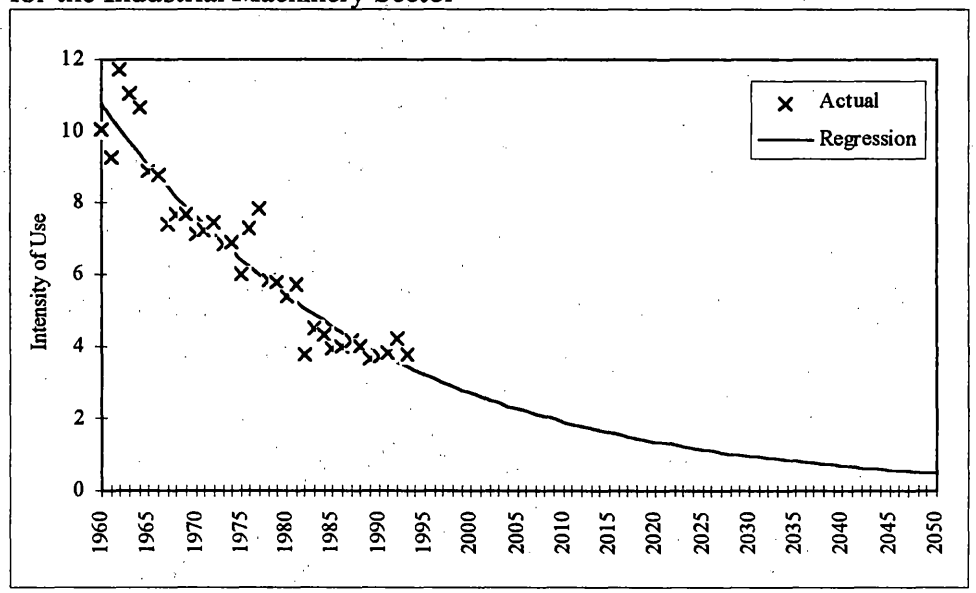
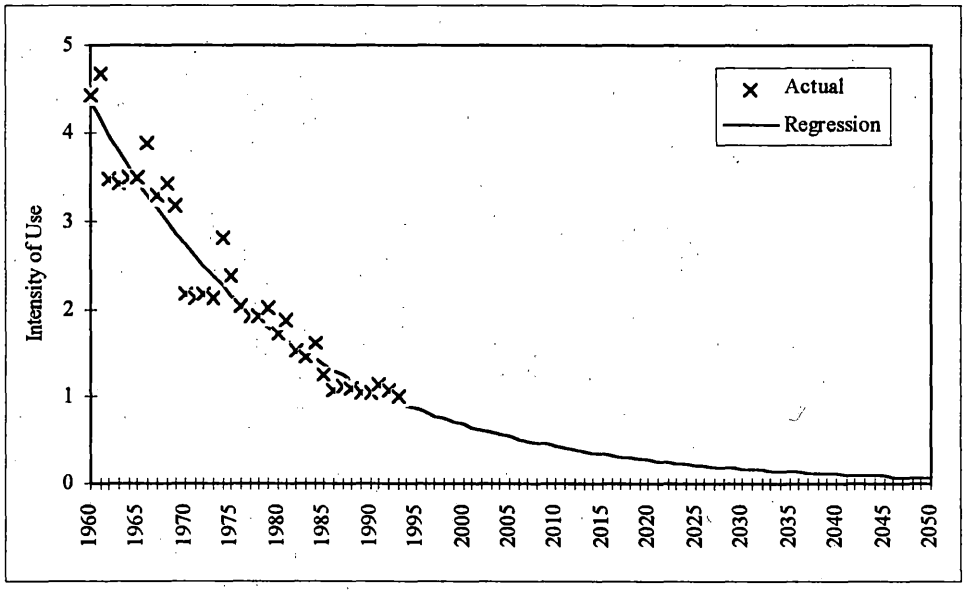


Chart 9: Intensity of Copper Use Trend in Tons per Million (1987) Dollars for the Consumer and General Sector



Sectoral GDP forecasts for 2020 and 2050, as pointed out in the previous section, are derived from three different growth scenarios. The first assumes each sector grows in the future at the pace recorded over the years 1960-73, a period of relatively rapid growth. The second assumes each sector grows in the future at the pace recorded over the years 1973-1993, a period of relatively slow growth. The third, the medium growth scenario, assumes each sector grows in the future at the pace recorded over the entire 1960-93 period. Table 2 reports these three rates for each sector and for the economy as a whole. It shows that the copper-intensive sectors with the sole exception of building and construction have grown more rapidly than the economy as a whole over the 1960-93 period. Using these growth rates, one can project the GDP for each sector for the years 2020 and 2050. The results--**step 4** of our procedures--are given in Tables 3 and 4.

Table 2: Average Annual GDP Growth Rates, in percent, by Sector and For the Economy as a Whole for 1960-1973 (High Growth), for 1973-1993 (Low Growth), and for 1960-1993 (Medium Growth)

	Low Rate	Medium Rate	High Rate
Building & Construction	1.99%	2.40%	2.88%
Electrical & Electronic	5.88%	7.07%	9.29%
Transportation	1.38%	3.54%	7.63%
Industrial Machinery	2.78%	3.55%	5.83%
Consumer & General	2.46%	4.67%	8.13%
Total GDP	2.14%	3.00%	4.25%

Table 3: GDP Forecasts in Billions of (1987) Dollars for 2020 by Sector

Sector	Low Growth	Medium Growth	High Growth
Building & Construction	729	812	921
Electrical & Electronic	1,479	2,001	3,482
Transportation	384	678	1,931
Industrial Machinery	223	273	491
Consumer & General	533	949	2,284

Table 4: GDP Forecasts in Billions of (1987) Dollars by Sector for 2050

Sector	Low Growth	Medium Growth	High Growth
Building & Construction	1,316.8	1,655.2	2,160.8
Electrical & Electronic	8,215.4	15,534.6	50,040.4
Transportation	579.5	1,927.1	17,536.3
Industrial Machinery	508.3	777.9	2,691.9
Consumer & General	1,106.0	3,732.8	23,828.7

Step 5 entails multiplying the forecasted GDP and intensity of use for each sector, which the two preceding steps have generated, and then adding the products to obtain point forecasts of total U.S. copper demand for the years 2020 and 2050. The results are shown in Tables 5 and 6. They are conditional forecasts, as noted earlier, as they depend on externally determined forecasts of sectoral GDP. As these tables show, the forecasts for future copper demand vary greatly depending on the anticipated growth in sectoral GDP.

Table 5: Forecasts for Copper Demand in Thousands of Metric Tons by Sector for 2020

Sector	Low Growth	Medium Growth	High Growth
Building & Construction	1,626	1,812	2,055
Electrical & Electronic	1,243	1,681	2,925
Transportation	384	679	1,932
Industrial Machinery	301	313	664
Consumer & General	144	256	617
Total Copper Demand	3,699	4,741	8,194

Table 6: Forecasts for Copper Demand in Thousand of Metric Tons by Sector for 2050

Sector	Low Growth	Medium Growth	High Growth
Building & Construction	2,278	2,863	3,738
Electrical & Electronic	2,054	3,884	12,510
Transportation	388	1,291	11,750
Industrial Machinery	244	373	1,292
Consumer & General	77	261	1,668
Total Copper Demand	5,042	8,673	30,958

The mean value and standard deviation for each sector's forecasted intensity of use for the 1960-93 period are given in Table 7. To accomplish **step 6,** the same information for the forecast years 2020 and 2050, which is needed for the Monte Carlo simulations, is estimated in the manner described in the previous section. These forecasts are reported in Table 8.

Table 7: Mean and Standard Deviation For Intensity of Use by Sector, 1960-1993

Sector	Mean	Standard Deviation
Building & Construction	3.10	0.41
Electrical & Electronic	5.36	2.25
Transportation	1.77	0.28
Industrial Machinery	6.48	2.46
Consumer & General	2.25	1.07

Table 8: Mean and Standard Deviation Forecasts For Intensity of Use by Sector For 2020 and 2050

	2020		2050	
	Mean	Standard Deviation	Mean	Standard Deviation
Building & Construction	2.23	0.29	1.73	0.23
Electrical & Electronic	0.84	0.35	0.25	0.10
Transportation	1.00	0.16	0.67	0.11
Industrial Machinery	1.35	0.51	0.48	0.18
Consumer & General	0.27	0.13	0.07	0.03

The next step in our procedures, **step 7**, requires the estimation of a correlation matrix that reflects how each sector's intensity of copper use varies over the 1960-93 period with changes in the intensity of copper use of other sectors. This matrix is shown in Table 9, and indicates, for example, that a 1 percent decrease in the intensity of copper use in the building and construction sector tends to be associated with a 0.69 percent decrease in the intensity of copper use in the transportation sector

Table 9: Correlation Coefficient Between Sectoral Intensities of Use, 1960-1993

	B&C	T	C&G	IM	EE
B&C	1.00	0.69	0.28	0.23	0.32
T	0.69	1.00	0.11	-0.08	0.24
C&G	0.28	0.11	1.00	0.40	0.11
IM	0.23	-0.08	0.40	1.00	0.45
EE	0.32	0.24	0.11	0.45	1.00

Monte Carlo simulation, **step 8**, generates a mean projection for copper demand in the United States, a standard deviation for this prediction, a minimum demand, and a maximum demand for each of the three growth scenarios (high, medium, and low) and for both forecast years (2020 and 2050). The results are reported in Table 10. Chart 10 provides a graphical representation of the six mean forecasts. Charts 11-16 show each of these forecasts along with their 90 percent confidence interval.

Table 10: Simulation Results for Copper Demand in Thousand Metric Tons for Low, Medium, and High Growth Scenarios for 2020 and 2050

Low Growth Scenario	2020	2050
Minimum Demand	1,451	1,927
Maximum Demand	6,173	8,569
Mean Demand	3,715	5,058
Standard Deviation	710	1,026
Medium Growth Scenario	2020	2050
Minimum Demand	1,841	3,041
Maximum Demand	7,876	15,564
Mean Demand	4,764	8,705
Standard Deviation	928	1,860
High Growth Scenario	2020	2050
Minimum Demand	3,036	11,611
Maximum Demand	13,680	53,480
Mean Demand	8,238	31,070
Standard Deviation	1,636	6,291

Chart 10: Copper Demand Forecasts for Low, Medium, and High Growth Scenario for 2020 and 2050

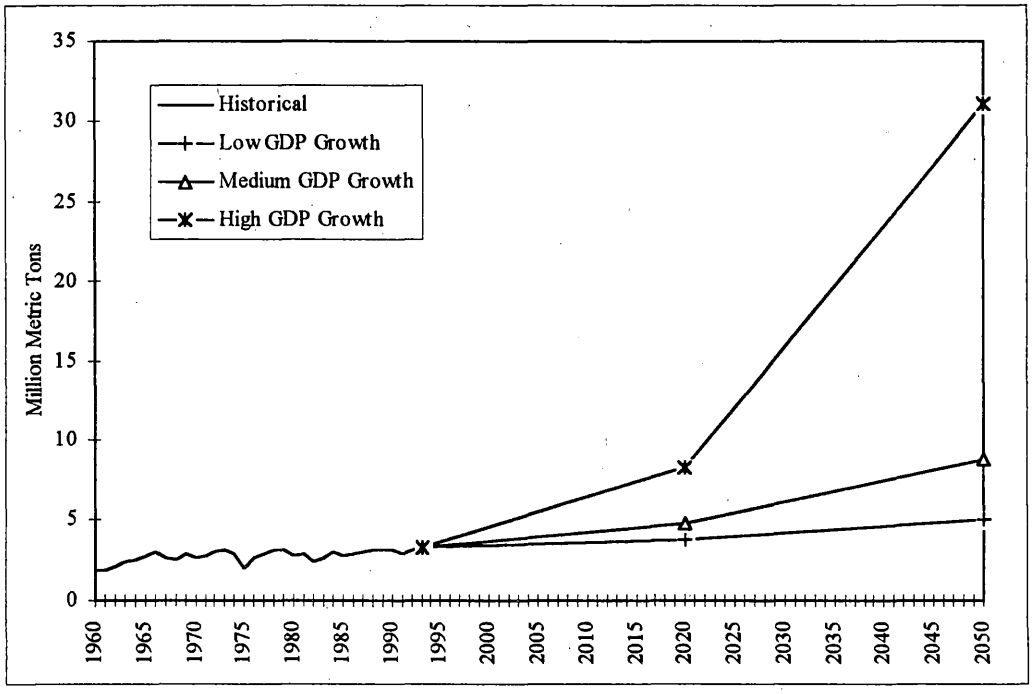


Chart 11: Copper Demand Forecast and 90 Percent Confidence Interval for Low Growth Scenario 2020

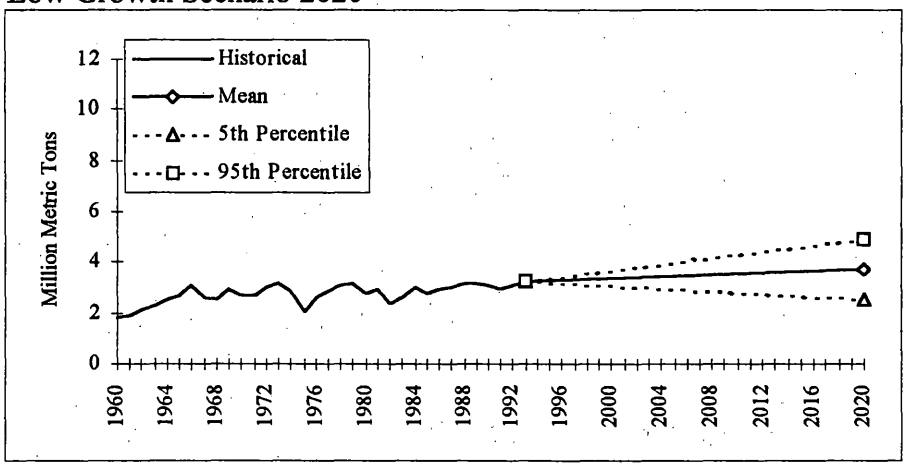


Chart 12: Copper Demand Forecast and 90 Percent Confidence Interval for Medium Growth Scenario 2020

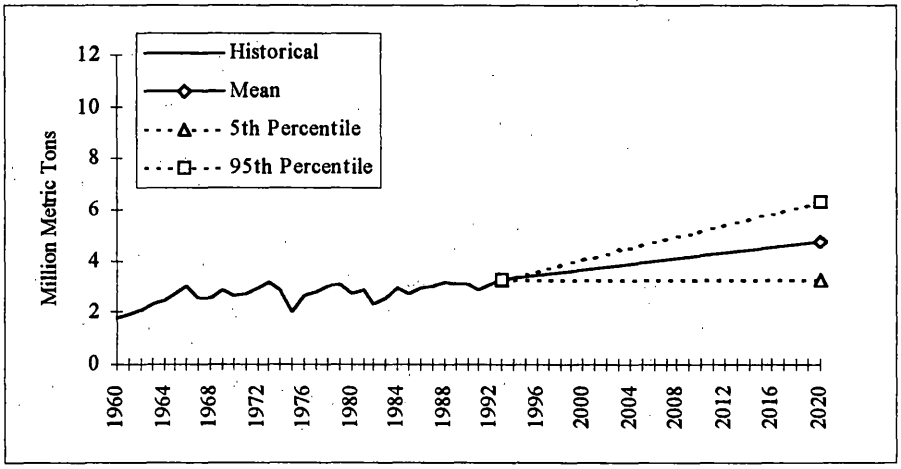


Chart 13: Copper Demand Forecast and 90 Percent Confidence Interval for High Growth Scenario 2020

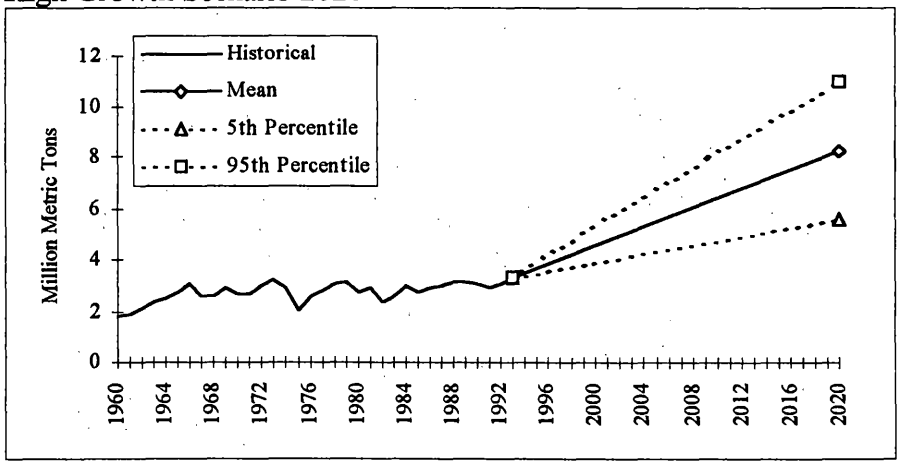


Chart 14: Copper Demand Forecast and 90 Percent Confidence Interval for Low Growth Scenario for 2050

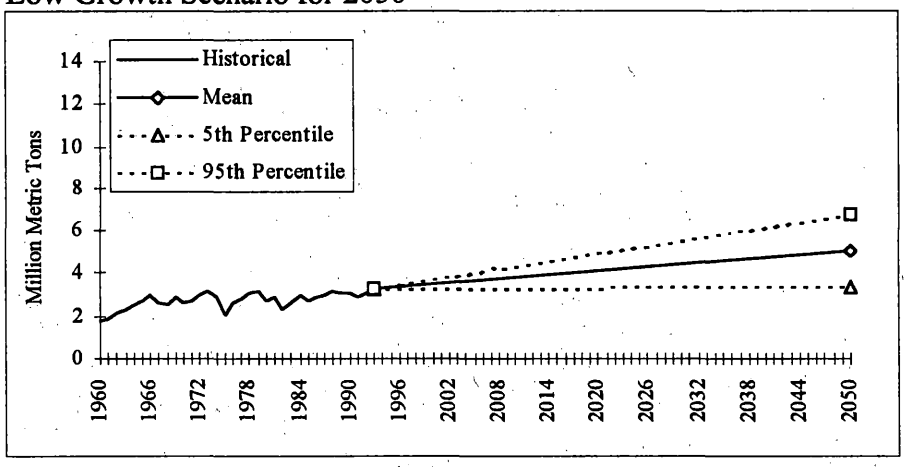


Chart 15: Copper Demand Forecast and 90 Percent Confidence Interval for Medium Growth Scenario for 2050

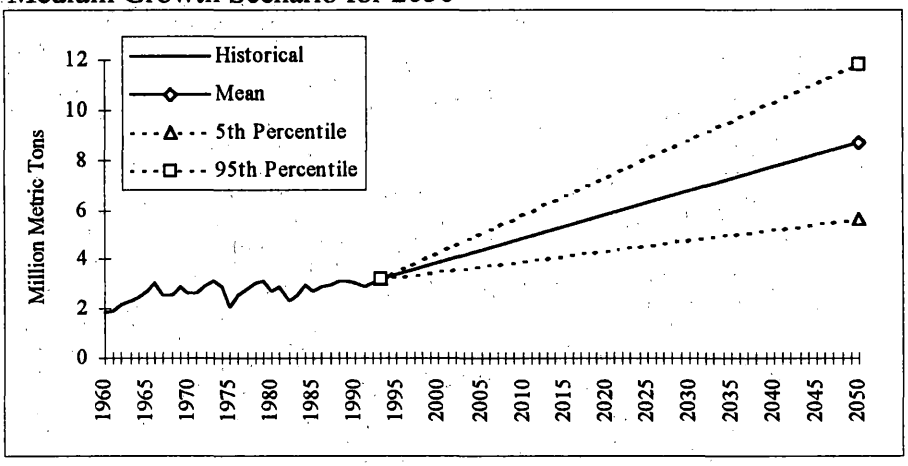
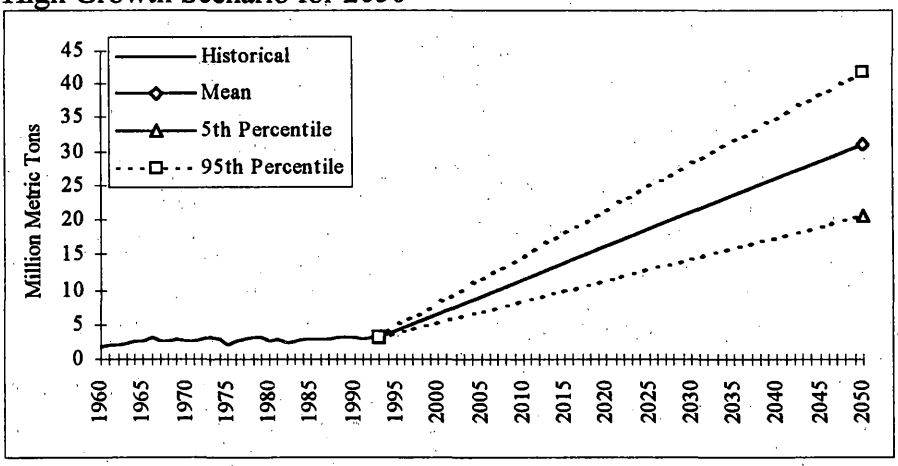


Chart 16: Copper Demand Forecast and 90 Percent Confidence Interval for High Growth Scenario for 2050



The sensitivity analysis, **step 9**, assesses how changes in the sectoral intensities of use affect the forecasts of future copper, and generates the correlation coefficients shown in Table 11 between the intensity of copper use for each sector and final copper demand. The figures in this table indicate that changes in the intensity of copper use in the electrical and electronic sector have the greatest impact on future copper demand. Specifically, the coefficient of 0.901 implies that a one percent increase in the intensity of copper use in this sector is associated with a 0.901 percent increase in total copper demand in the forecast year 2050. The results also imply that changes in the intensity of copper use within the consumer and general sector have little impact on overall copper demand.

These findings are not surprising, since building and construction is the largest sector and electrical and electronic the second largest sector among those considered (Chart 3). While the transportation sector and the consumer and general sector are almost as large as the electrical and electronic sector, they have the lowest intensities of copper use (Chart 2), which also explains their low correlation with total copper demand.

Table 11: Correlation Coefficients Between Sectoral Intensity of Use and Forecasted Copper Demand

Sector	2020	2050
Electrical & Electronic	0.901	0.932
Building & Construction	0.624	0.596
Industrial Machinery	0.573	0.514
Transportation	0.436	0.427
Consumer & General	0.293	0.209

V. Sand and Gravel

The procedures used to forecast the U.S. demand for sand and gravel in 2020 and 2050 are similar to those used in the previous section for copper. However, in the case of sand and gravel, there is only one major consuming sector, building and construction. This sector accounted for over 95 percent of total sand and gravel consumption in the United States over the 1960-93 period.

The intensity of sand and gravel use in the building and construction sector is shown in Chart 17 for the years 1960-93. The data for sand and gravel consumption and for the GDP of the Building and Construction sector, on which the intensity of use figures are based, are given in Appendix 3.1 along with their sources. They are illustrated in Charts 18 and 19.

Chart 17: Intensity of Sand and Gravel Use for the Building and Construction Sector in Tons Per Thousand (1987) Dollars, 1960-1993

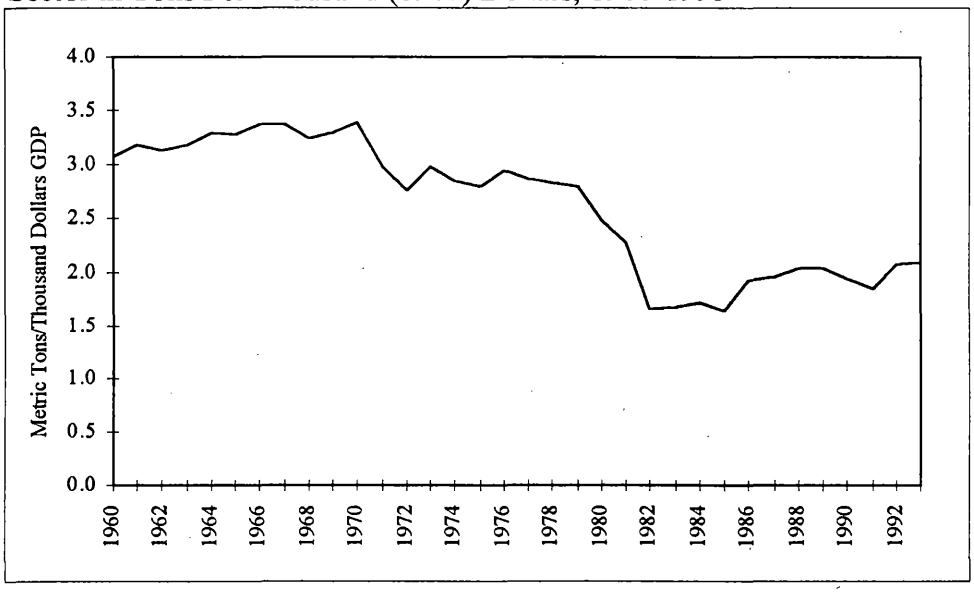


Chart 18: Gross Domestic Production for Building and Construction Sector, 1960-1993

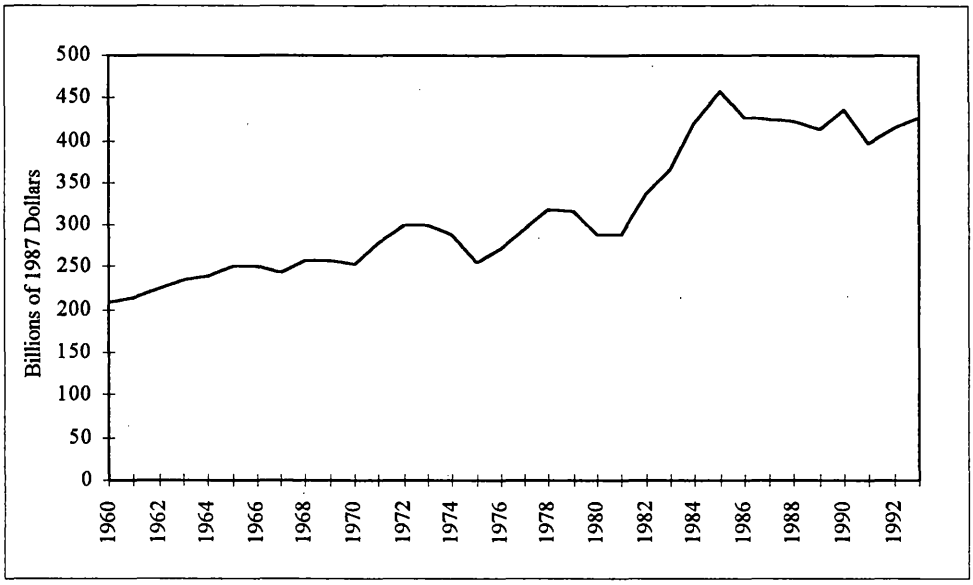


Chart 19: Sand and Gravel Consumption by the Building and Construction Sector, 1960-1993

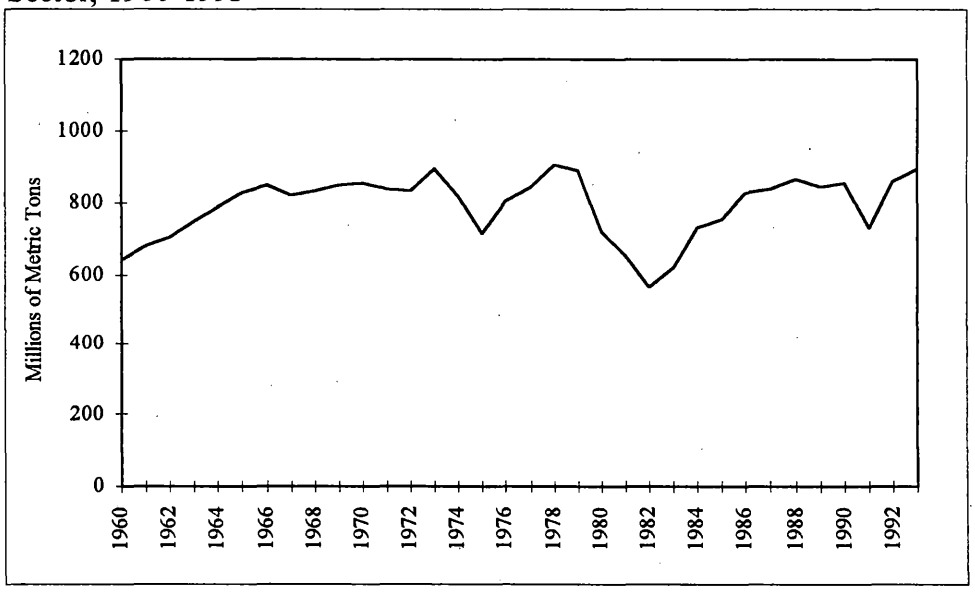
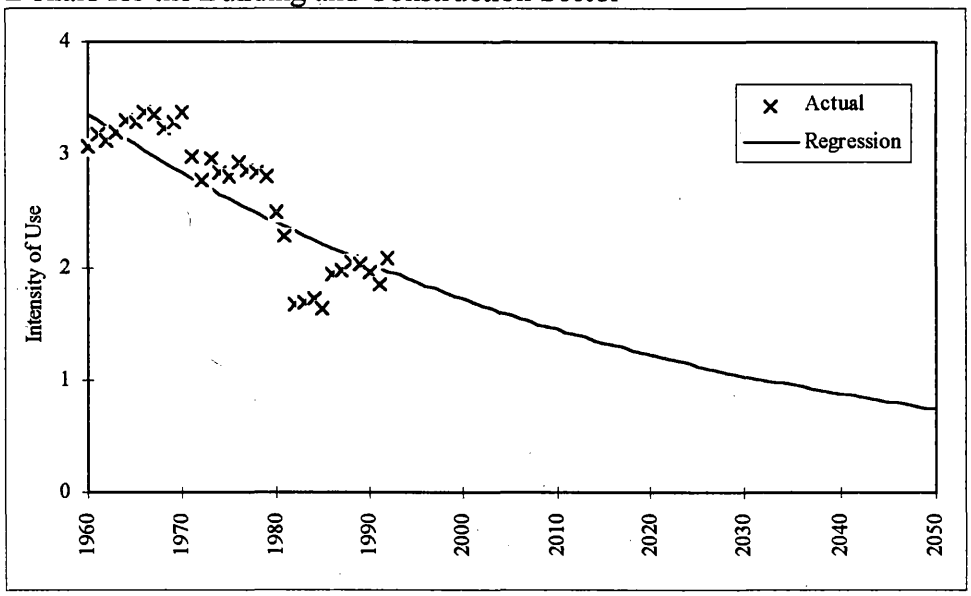


Chart 20 shows the semi-log functional form that best fits the sand and gravel intensity of use data over the 1960-93 period. The regression results determining the curve shown are reported in Appendix 4.1. Extrapolating the curve into the future produces a predicted value of sand and gravel intensity of use in the year 2020 of 1.23 tons per thousand (1987) dollars of Building and Construction GDP. The figure declines to 0.74 by 2050.

Chart 20: Intensity of Sand and Gravel Use Trend in Tons per Thousand (1987) Dollars for the Building and Construction Sector



Again, three different Building and Construction GDPs are considered for both forecast years. The first, based on a low growth scenario, assumes this sector will expand in the future at an average annual rate of 1.99 percent, as it did during the 1973-93 period. The second, based on a high growth scenario, assumes this sector will expand at an average annual rate of 2.88 percent, as it did during the 1960-73 period. The third, based on a medium growth scenario, assumes this sector will expand at an average annual rate of

2.40 percent, as it did over the entire 1960-93 period. The forecasted Building and Construction GDPs associated with these growth rates are shown in Table 12 for the years 2020 and 2050.

Table 12: Building & Construction GDP Forecasts in Billions of (1987) Dollars

	2020	2050
Low Growth	729	1,317
Medium Growth	813	1,655
High Growth	922	2,161

The forecasts of intensity of use--1.23 for 2020 and 0.74 for 2050--were next multiplied by the predicted Building and Construction GDPs reported in Table 12. The resulting products are the six demand forecasts for sand and gravel shown in Table 13.

Table 13: Forecasts for Sand and Gravel Demand in Millions of Metric Tons for the Building and Construction Sector for 2020 and 2050

	2020	2050
Low Growth	897	975
Medium Growth	1,000	1,225
High Growth	1,134	1,599

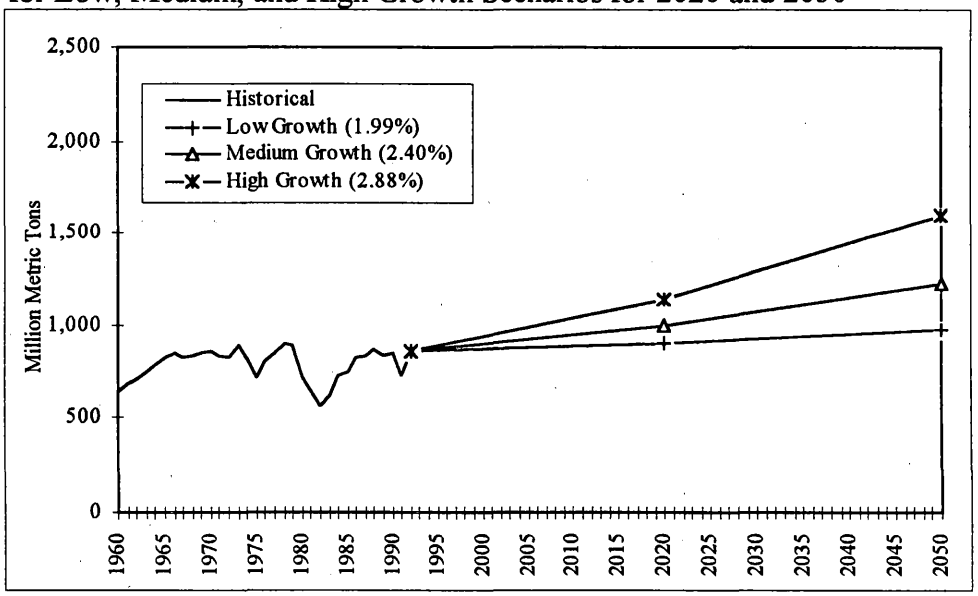
Standard deviations for the forecasted values of intensity of sand and gravel use were estimated in the same manner as for copper. The results--0.29 for 2020 and 0.17 for 2050--were taken into account in the Monte Carlo simulation of again 2000 iterations that produced sand and gravel demand estimates for these two years reported in Table 14. The mean demand estimates shown in this table are the same as the forecasts given in Table 13, which were derived by simply multiplying the forecasted intensity of use by the predicted Building and Construction GDP. This is because the correlation between major consumer sectors is not a factor in the case of sand and gravel since Building and Construction is the

only major sand and gravel consuming sector. As with copper, the high growth scenario produces the least certain forecast as reflected by a larger standard deviation.

Table 14: Simulation Results For Sand and Gravel Demand in Millions of Metric Tons for Low, Medium, and High Growth Scenarios for 2020 and 2050

Low Growth Scenario	2020	2050
Minimum Demand	166	238
Maximum Demand	1,671	1,810
Mean Demand	897	975
Standard Deviation	209	223
Medium Growth Scenario	2020	2050
Minimum Demand	113	264
Maximum Demand	1,782	2,237
Mean Demand	1,000	1,225
Standard Deviation	233	280
High Growth Scenario	2020	2050
Minimum Demand	201	158
Maximum Demand	2,132	2,865
Mean Demand	1,134	1,599
Standard Deviation	264	365

Chart 21: Mean Forecasts for Sand and Gravel Demand in Millions of Metric Tons for Low, Medium, and High Growth Scenarios for 2020 and 2050



The mean forecasts, which Chart 21 illustrates, predict a very modest growth in the U.S. demand for sand and gravel over the next half century if either the low or medium growth scenario prevail. The reason for this is that under these scenarios the positive effect of the growth of the Building and Construction sector on the demand for sand and gravel is largely offset by the negative effect of declining intensity of use. Under the high growth scenario, the projected growth in demand is more robust. Charts 22 through 27 show the 90 percent confidence interval around the six reported forecasts for sand and gravel demand.

Chart 22: Sand and Gravel Demand Forecast and 90 Percent Confidence Interval for Low Growth Scenario for 2020

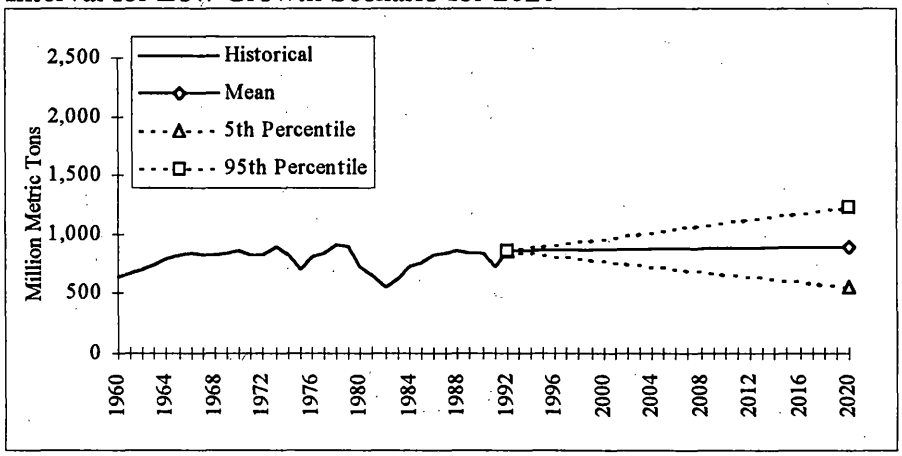


Chart 23: Sand and Gravel Demand Forecast and 90 Percent Confidence Interval for Medium Growth Scenario for 2020

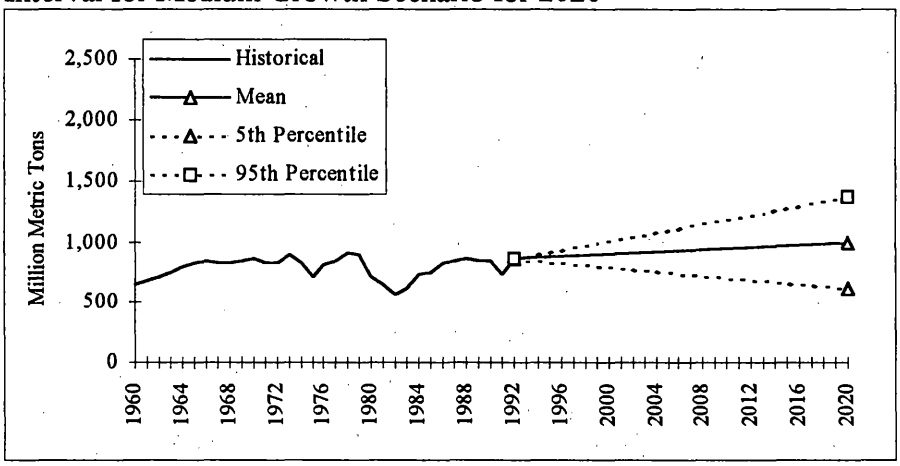


Chart 24: Sand and Gravel Demand Forecast and 90 Percent Confidence Interval for High Growth Scenario for 2020

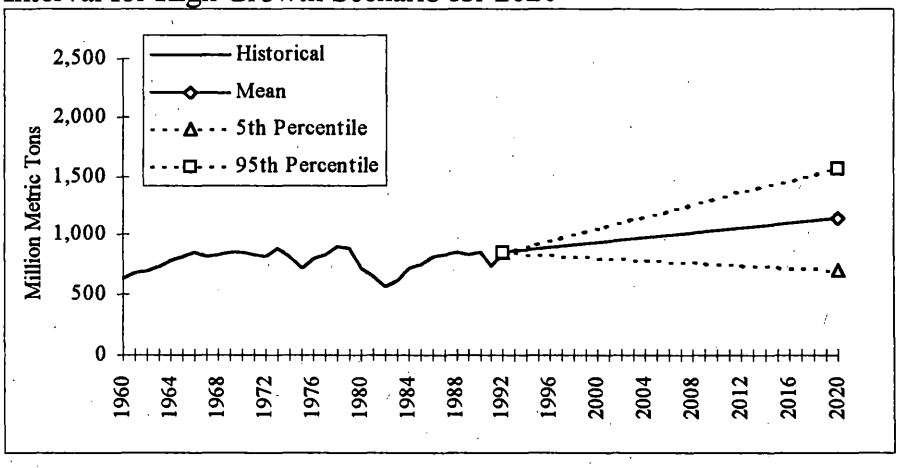


Chart 25: Sand and Gravel Demand Forecast and 90 Percent Confidence Interval for Low Growth Scenario for 2050

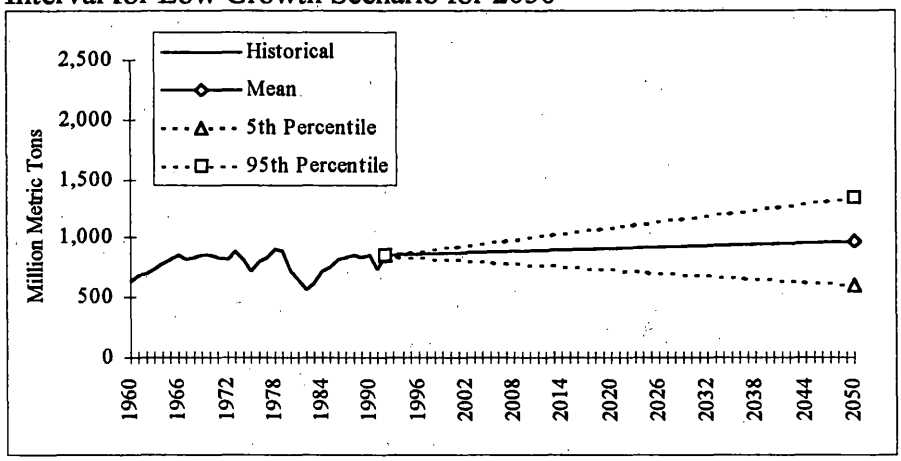


Chart 26: Sand and Gravel Demand Forecast and 90 Percent Confidence Interval for Medium Growth Scenario for 2050

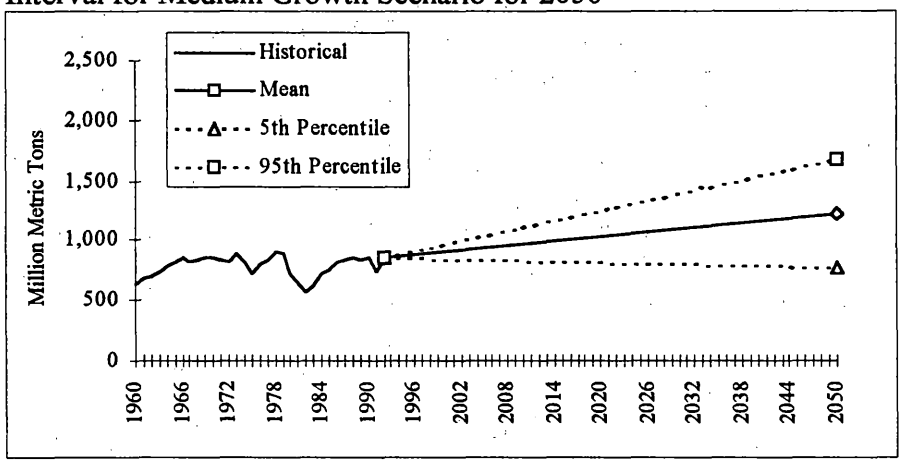
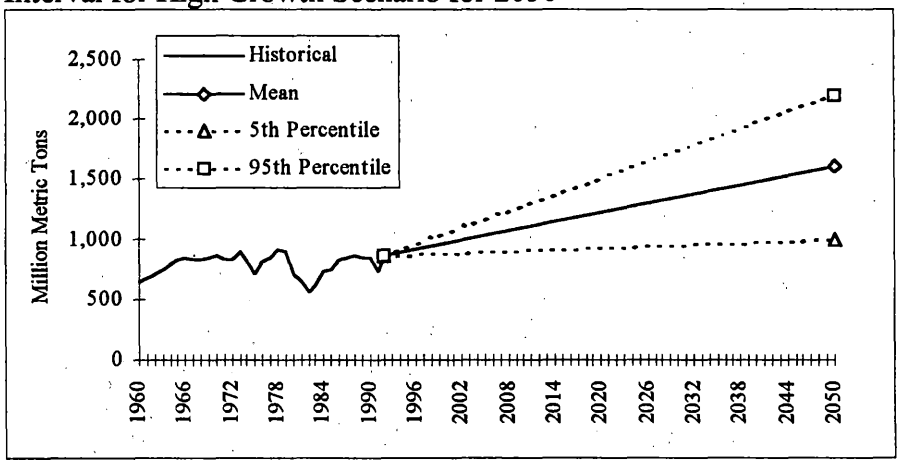


Chart 27: Sand and Gravel Demand Forecast and 90 Percent Confidence Interval for High Growth Scenario for 2050



VI. Conclusions

The preceding sections have described a set of procedures for forecasting the long-run demand for mineral commodities, and used these procedures to predict the demand for copper and for sand and gravel in the United States in the years 2020 and 2050. The proposed procedures assume sectoral GDP predictions are available from independent marcoeconomic forecasting services. They couple this exogenous information with extrapolations of intensity of mineral use by sector, and generate forecasts with confidence intervals using Monte Carlo simulations.

These procedures have a number of advantages. First, they are relatively easy and inexpensive to use, and can be carried out quickly. Second, they are transparent. The steps involved are clear and easy to understand. Third, they explicitly try to capture the effect on future demand of new technology and other forces tending reduce the intensity of mineral use over time. Fourth, they take into account any tendency for the intensity of use trend in one major consumer sector to be correlated with comparable trends in other sectors. Fifth, they allow the macroeconomic forecasts of sectoral GDP to be carried out independently by individuals or organizations with particular expertise in this field. Sixth, they provide a probability distribution or confidence interval in addition to point forecasts. Seventh, they can generate demand forecasts for mineral commodities by major consuming sector as well as for the economy as a whole. Eighth, they easily accommodate the use of sensitivity analysis, which in turns identifies the more important determinants of future demand.

As with any type of forecasting technique, the proposed procedures do suffer from several shortcomings. First and probably the most serious, they assume the sectoral intensities of use for the commodity whose demand is being forecasted will not only decline in the future, but do so at an exponential rate that can be estimated on the basis of recent historical experience. This is a strong assumption. Intensity of use for some mineral commodities is known to be rising in a number of developing countries. Even in the United States, the intensity of use for some metals has shown a modest increase since 1993. This may simply reflect a short-run cyclical perturbation. If not, however, the use of our procedures would likely underestimate future demand.

Second, the procedures provide no underlying cause-and-effect model or explanation for the declining trend expected in intensity of use other than noting in passing the net effect on balance of new resource-saving technology. Over the long run, technological change is one of the most important determinants, perhaps the most important determinant, of the demand for mineral commodities. A great deal of uncertainty surrounds the generation and resulting consequences of new technology.

Third, the procedures take as given the externally determined macroeconomic forecasts for future sectoral GDPs, and thus as noted produce conditional forecasts. No attempt is made in the preceding pages to take account of the uncertainty associated with these macroeconomic forecasts. This could be done but the cost in terms of the additional information required would be high. Specifically, standard deviations for the sectoral GDP forecasts along with correlation coefficients between the sectoral GDPs would be required.

These shortcomings, like those associated with other long-run forecasting approaches, are useful reminders that considerable uncertainty surrounds any prediction of mineral commodity demand into the distant future. Moreover, this uncertainty is inherent in the nature of the activity, and cannot be eliminated by using one or another forecasting technique.

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Appendix 1.1

Year	Gross Domestic Product by Sector in Billions of (1987) Dollars				
	Building & Construction	Electrical & Electronic	Transportation	Industrial Machinery	Consumer & General Products
1960	209.1	51.6	114.7	40.9	70.2
1961	213.9	55.6	109.1	43.7	69.4
1962	225.8	58.7	122.6	42.9	79.0
1963	233.7	64.7	135.3	47.2	82.1
1964	238.5	74.6	143.7	54.4	94.4
1965	250.8	80.6	170.2	58.7	95.6
1966	251.2	100.8	191.3	67.5	115.1
1967	244.0	106.7	183.3	68.7	122.6
1968	257.5	117.1	219.0	66.7	125.4
1969	258.3	124.2	220.2	71.8	138.5
1970	253.2	131.0	185.3	68.7	155.2
1971	279.4	132.9	224.6	64.3	156.7
1972	300.0	145.2	251.2	70.6	183.3
1973	300.0	161.1	279.4	82.5	189.3
1974	288.5	108.6	180.3	73.2	137.8
1975	255.6	105.5	181.5	62.1	132.8
1976	273.1	114.1	193.4	60.1	160.3
1977	294.6	125.0	222.2	60.6	172.9
1978	318.2	172.4	222.7	88.6	193.1
1979	317.2	192.9	220.7	91.4	195.9
1980	289.0	209.8	190.6	85.3	189.3
1981	288.0	221.9	191.4	85.6	189.9
1982	338.9	127.7	133.4	101.4	187.4
1983	367.0	148.5	165.3	91.2	194.3
1984	421.0	179.9	196.3	104.2	214.4
1985	458.2	209.9	214.6	102.7	227.3
1986	428.3	237.3	201.8	102.0	265.0
1987	425.5	261.3	198.2	101.9	271.2
1988	422.9	295.5	213.1	112.4	286.6
1989	413.5	323.6	208.7	120.2	289.2
1990	436.5	213.7	243.2	108.2	269.1
1991	396.4	228.4	235.7	98.0	249.1
1992	414.5	256.8	248.4	95.4	258.9
1993	428.3	316.4	265.3	106.5	276.8

Source: United States Bureau of Economic Analysis, *Survey of Current Business.*

Appendix 1.2

Year	Copper Consumption by Sector in Metric Tons				
	Building & Construction	Electrical & Electronic	Transportation	Industrial Machinery	Consumer & General Products
1960	434,014	561,905	266,213	409,977	310,658
1961	489,342	548,299	269,388	404,989	325,170
1962	695,238	504,762	250,340	503,401	274,376
1963	736,508	537,415	261,678	522,449	282,540
1964	822,676	629,478	289,796	580,499	331,519
1965	965,986	671,655	335,147	522,449	334,240
1966	1,022,676	764,626	370,975	591,383	446,712
1967	853,061	654,422	305,215	508,844	402,721
1968	845,351	655,782	324,263	511,565	430,385
1969	934,240	776,417	337,868	551,927	439,456
1970	840,816	726,531	278,005	487,075	338,776
1971	916,553	738,322	322,902	465,760	335,147
1972	1,001,361	779,138	359,184	525,170	400,454
1973	1,083,447	852,608	418,141	562,812	405,442
1974	877,551	780,499	351,020	505,669	388,209
1975	705,669	533,333	286,168	372,336	317,460
1976	849,887	678,005	394,104	437,188	329,705
1977	962,812	768,254	427,664	473,469	334,694
1978	1,039,002	817,687	422,222	516,553	374,603
1979	1,052,154	868,481	411,791	525,624	394,104
1980	877,551	755,556	288,889	457,596	327,438
1981	923,810	803,628	322,902	491,610	358,277
1982	842,177	675,283	257,596	385,034	285,714
1983	996,372	687,982	321,088	410,884	283,447
1984	1,164,626	770,522	404,082	451,247	343,764
1985	1,173,243	667,574	369,161	407,256	283,900
1986	1,233,107	695,238	369,161	407,710	280,726
1987	1,381,859	740,590	370,522	427,211	303,401
1988	1,318,821	752,834	382,766	450,340	315,193
1989	1,272,562	743,764	358,730	439,002	299,320
1990	1,220,862	756,463	338,776	404,535	281,633
1991	1,180,499	693,878	321,088	376,417	280,726
1992	1,227,664	747,392	340,136	400,907	273,923
1993	1,298,866	740,136	377,324	400,000	274,830

Source: Copper Development Association.

Appendix 1.3

Year	Intensity of Copper Use by Sector in Metric Tons Per Million (1987) Dollars GDP				
	Building & Construction	Electrical & Electronic	Transportation	Industrial Machinery	Consumer & General Products
1960	2.08	10.89	2.32	10.03	4.42
1961	2.29	9.87	2.47	9.28	4.68
1962	3.08	8.59	2.04	11.75	3.47
1963	3.15	8.31	1.93	11.06	3.44
1964	3.45	8.44	2.02	10.68	3.51
1965	3.85	8.34	1.97	8.90	3.49
1966	4.07	7.59	1.94	8.77	3.88
1967	3.50	6.13	1.66	7.41	3.28
1968	3.28	5.60	1.48	7.67	3.43
1969	3.62	6.25	1.53	7.68	3.17
1970	3.32	5.55	1.50	7.09	2.18
1971	3.28	5.55	1.44	7.20	2.14
1972	3.34	5.36	1.43	7.43	2.18
1973	3.61	5.29	1.50	6.82	2.14
1974	3.04	7.19	1.95	6.91	2.82
1975	2.76	5.05	1.58	6.00	2.39
1976	3.11	5.94	2.04	7.28	2.06
1977	3.27	6.15	1.92	7.81	1.94
1978	3.27	4.74	1.90	5.83	1.94
1979	3.32	4.50	1.87	5.75	2.01
1980	3.04	3.60	1.52	5.36	1.73
1981	3.21	3.62	1.69	5.74	1.89
1982	2.48	5.29	1.93	3.80	1.52
1983	2.72	4.63	1.94	4.50	1.46
1984	2.77	4.28	2.06	4.33	1.60
1985	2.56	3.18	1.72	3.96	1.25
1986	2.88	2.93	1.83	4.00	1.06
1987	3.25	2.83	1.87	4.19	1.12
1988	3.12	2.55	1.80	4.01	1.10
1989	3.08	2.30	1.72	3.65	1.04
1990	2.80	3.54	1.39	3.74	1.05
1991	2.98	3.04	1.36	3.84	1.13
1992	2.96	2.91	1.37	4.20	1.06
1993	3.03	2.34	1.42	3.76	0.99

Appendix 2.1

Sectoral Intensity of Copper Use Regression Results

Electrical and Electronic Sector

Equation: $\ln(IU_{it}) = 82.108 - 0.041T_t$

	Coef	S.E.	t-ratio
Constant	82.11	7.06	11.64
T_t	-0.041	0.004	-11.43
R-squared	0.89		
D.W.	1.88		
Rho	0.33		

Transportation Sector

Equation: $\ln(IU_{it}) = 27.37 - 0.014T_t$

	Coef	S.E.	t-ratio
Constant	27.37	10.85	2.52
T_t	-0.014	0.005	-2.47
R-squared	0.58		
D.W.	1.92		
Rho	0.67		

Industrial Machinery Sector

Equation: $\ln(IU_{it}) = 70.15 - 0.034T_t$

	Coef	S.E.	t-ratio
Constant	70.15	4.94	14.19
T_t	-0.034	0.003	-13.60
R-squared	0.92		
D.W.	1.97		
Rho	0.30		

Consumer and General Sector

Equation: $\ln(IU_{it}) = 92.89 - 0.047T_t$

	Coef	S.E.	t-ratio
Constant	92.89	5.33	17.44
T_t	-0.047	0.003	-17.34
R-squared	0.95		
D.W.	1.87		
Rho	0.34		

Building and Construction Sector

Equation: $\ln(IU_{it}) = 17.71 - 0.008T_t$

	Coef	S.E.	t-ratio
Constant	17.71	5.20	3.41
T_t	-0.008	0.003	-3.19
R-squared	0.45		
D.W.	1.76		
Rho	0.30		

Appendix 3.1

Year	Consumption of Sand and Gravel in the Building and Constuction Sector in Million Metric Tons	Building and Construction Sector Gross Domestic Product in Billions of (1987) Dollars	Intensity of Sand and Gravel Use in the Building and Construction Sector in Metric Tons per Thousand (1987) Dollars
1960	643	209.1	3.08
1961	681	213.9	3.19
1962	705	225.8	3.12
1963	746	233.7	3.19
1964	788	238.5	3.30
1965	824	250.8	3.29
1966	848	251.2	3.38
1967	821	244.0	3.37
1968	833	257.5	3.23
1969	850	258.3	3.29
1970	857	253.2	3.38
1971	834	279.4	2.99
1972	830	300.0	2.77
1973	893	300.0	2.98
1974	821	288.5	2.85
1975	716	255.6	2.80
1976	803	273.1	2.94
1977	843	294.6	2.86
1978	904	318.2	2.84
1979	888	317.2	2.80
1980	719	289.0	2.49
1981	653	288.0	2.27
1982	564	338.9	1.66
1983	619	367.0	1.69
1984	729	421.0	1.73
1985	753	458.2	1.64
1986	826	428.3	1.93
1987	839	425.5	1.97
1988	864	422.9	2.04
1989	841	413.5	2.03
1990	852	436.5	1.95
1991	731	396.4	1.84
1992	859	414.5	2.07
1993	895	428.3	2.09

Sources:

United States Bureau of Mines, *Minerals Yearbook.*

United States Bureau of Economic Analysis, *Survey of Current Business.*

Appendix 4.1

Intensity of Sand and Gravel Use Regression Result

Equation: $\ln(IU_{it}) = 34.10 - 0.017T_t$

	Coef	S.E.	t-ratio
Constant	34.10	9.95	3.43
T_t	-0.017	0.005	-3.33
R-squared	0.91		
D.W.	1.67		
Rho	0.81		